RESEARCH DEPARTMENT

A phase-corrected video "notch" filter

TECHNOLOGICAL REPORT No. T-173

UDC 621.372.543.39 1966/38

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

A PHASE-CORRECTED VIDEO "NOTCH" FILTER

Technological Report No. T-173
UDC 621.372.543.39 1966/38

R.E. Davies, M.A.
Miss G. Edmondson, B.Sc., Grad.I.E.E.

D. Maurice

for Head of Research Department

Technological Report No. T-173

A PHASE-CORRECTED VIDEO ''NOTCH'' FILTER

July 1966

Technological Report No. T-173
UDC 621.372.543.39 1966/38

A PHASE-CORRECTED VIDEO "NOTCH" FILTER

SUMMARY

Video "notch" filters are used in television apparatus to suppress unwanted spectral components in the video-frequency band; an important application is the suppression of signal components at the colour-subcarrier frequency in the luminance channel of colour television equipment. However, the presence of a notch filter results in "ringing" whenever transients are present and thus impairs the displayed picture. In this report a new form of notch filter is described which is phase compensated. The "ringing" is therefore reduced in amplitude and distributed approximately equally on either side of a transition with a consequent reduction of picture impairment.

1. INTRODUCTION

Video notch filters are used in television apparatus for a number of purposes including the suppression of the colour-subcarrier components of a composite video colour signal; this process occurs in the separation of the luminance and chrominance information of a composite colour signal. The presence of a notch filter produces, on a displayed colour picture, "ringing" at vertical luminance transitions and subcarrier dot-patterns at vertical chrominance transitions, and the design of the filter should be such that the visibilities of these disturbances are minimised. Conventional forms of notch filter produce a damped oscillation immediately following a vertical luminance transition and dot-patterns that similarly follow a chrominance transition; a reduction of picture impairment would result if the ringing and other patterns were spread symmetrically on either side of such transitions. This would necessitate the use of a phase-corrected notch filter, i.e., a filter having a response/frequency characteristic similar to that of a conventional notch filter but having constant group-delay in the passband.

It would be difficult to equalise the group-delay of a conventional notch filter using all-pass networks because the total delay of the compensating circuit would be large (at least of the order of ten picture elements) and, in the region of the notch, rapid changes of group-delay would have to be compensated. This method is therefore impractical since it would require a very large number of all-pass correcting sections. A practical method is, however, proposed[1] in this report, in which the video-frequency signal is divided between two paths. In one path the signal is band-limited so that only frequencies in the region requiring attenuation are transmitted by means of a circuit that introduces a substantially constant group-delay. In the other path there is no band limitation and the whole signal is delayed by such a time that spectral components in the region requiring attenuation are in phase opposition with the corresponding spectral components derived from the first path. The outputs of the two paths are added so that in the final signal the required frequency band is attenuated whilst, at the same time, the group-delay remains nearly constant.

2. DESIGN PRINCIPLES

A block schematic of the notch filter is shown in Fig. 1 and it will be seen that the signal components having frequencies passed by the band-pass filter must cancel with the corresponding components of the signal passed through the delay *T*.

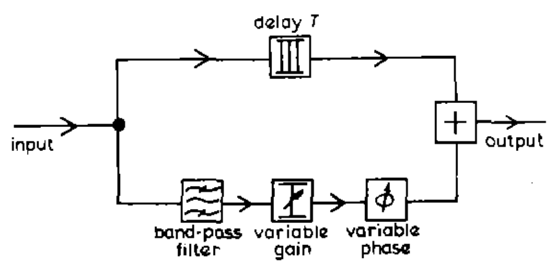

Fig. 1 - Schematic of notch filter

Thus, the components at these frequencies must be in phase opposition and since the delay path is arranged to have constant group-delay, the band-pass filter must, if possible, have a group-delay of the same value. It is then only necessary to arrange that the signals through the two paths are in phase opposition and that the relative gain of the two paths gives the required degree of cancellation at the centre frequency of the attenuation band. The variable phase shifter (which, once adjusted, must introduce constant group-delay within the passband of the filter) and the variable gain control, both shown in Fig. 1, enable separate adjustments of phase and gain to be made to achieve phase opposition and the required degree of attenuation.

The band-pass filter must be designed to have substantially constant group-delay and a response/frequency characteristic corresponding to the desired bandwidth of the notch. If the frequencies at which the response of the notch is -3 dB with respect to the maximum are specified, these will correspond approximately to an attenuation of 10 dB* in the response/frequency characteristic of the band-pass filter.

Fig. 2(*a*) shows the equivalent circuit of the simplest form of band-pass filter (a first order circuit). In the circuit of Fig. 2(*a*), writing p for jω, the output voltage V_{out}, is given by:

$$V_{out} = \frac{1}{g + pC + 1/pL} \cdot I \qquad (1)$$

Replacing ω by $\omega_0 + x\,\omega_b/2$, where $\omega_0/2\pi$ is the centre frequency so that $LC\omega_0^2 = 1$, and assuming that ω_b (the bandwidth bounded by the frequencies at which the notch response is -3 dB with respect to its maximum) is small compared with ω_0, so that $(\omega_b/\omega_0)^2$ is negligible, it can be shown that:

$$pC + \frac{1}{pL} \simeq j\omega_b C x$$

and the output voltage can therefore be written:

$$V_{out} = \frac{1}{1 + (jx\omega_b C/g)} \cdot \frac{I}{g} \qquad (2)$$

In Equation (2) the response at:

$$\omega = \omega_0 \ (x = 0)$$

* Assuming that the notch is also specified to have substantially zero response at the centre frequency of the band-pass filter.

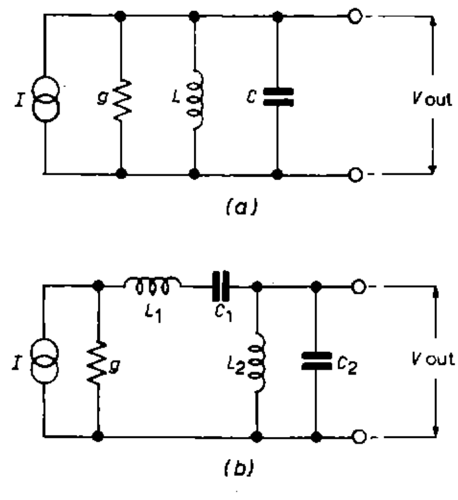

Fig. 2 - Equivalent circuits of band-pass filters

(*a*) First-order filter (*b*) Second-order filter

is I/g and frequencies at which the response is required to be -10 dB can be conveniently taken as:

$$\omega_0 \pm \tfrac{1}{2}\omega_b \ (x = \pm 1)$$

It follows that:

$$1 + (\omega_b\, C/g)^2 = 10$$

and that:

$$\omega_b\, C/g = 3$$

The circuit component values (apart from g which results in a multiplying factor independent of frequency) are therefore determined by the bandwidth and centre frequency required for the notch and it is impossible to adjust them so as to obtain a constant group-delay.

In the circuit of Fig. 2(*b*) a more complicated second-order filter* is shown. If we make:

$$L_1 C_1 \omega_0^2 = L_2 C_2 \omega_0^2 = 1$$

then $pL_1 + (1/pC_1)$ (the series impedance) $\simeq j\,\omega_b\, L_1\, x$ and $pC_2 + (1/pL_2)$ (the shunt admittance $\simeq j\,\omega_b\, C_2\, x$.

It may be shown that:

$$V_{out} = \frac{1}{1 + (\omega_b\, C_2\, jx/g) - \omega_b^2\, C_2 L_1 x^2} \cdot \frac{I}{g} \qquad (3)$$

* There are a number of similar cicuits essentially equivalent to Fig. 2(*b*), including the familiar "band-pass coupled pair". Almost identical methods of analysis may be applied to them.

For convenience, we may write:

$$V_{out} = \frac{1}{1 + \alpha jx - \beta x^2} \cdot \frac{I}{g} \qquad (4)$$

where $\alpha = (\omega_b\, C_2/g)$, $\beta = \omega_b{}^2\, C_2\, L_1$

If α and β are determined, the network components will be specified apart from g which, as before, results in a multiplying factor independent of frequency. As in the case of the first order filter of Fig. 2(*a*), the frequencies at which the response of the band-pass circuit is -10 dB relative to that at ω_0 can be taken to correspond to $x = \pm 1$. It can then be shown that:

$$(1 - \beta)^2 + \alpha^2 = 10 \qquad (5)$$

A further equation is needed to determine α and β uniquely and this may be found by specifying that the group-delay is maximally flat for small values of x. If ϕ is the phase shift due to the network, then the group-delay will be:

$$-\frac{d\phi}{d\omega} = -\frac{2}{\omega_b}\frac{d\phi}{dx}$$

$$\text{since } \omega = \omega_0 + \tfrac{1}{2}\omega_b x \qquad (6)$$

Using the relationship of (6), the group-delay of the band-pass filter can be shown to be:

$$-\frac{d\phi}{d\omega} = \frac{2}{\omega_b}\,\frac{\alpha + \alpha\beta x^2}{(1 - \beta x^2)^2 + (\alpha x)^2} = \frac{2\alpha}{\omega_b}\,\frac{1 + \beta x^2}{1 + (\alpha^2 - 2\beta)\,x^2 + \beta^2 x^4} \qquad (7)$$

The condition for this expression to be maximally flat provides the further equation needed to determine α and β and is:

$$\alpha^2 = 3\beta \qquad (8)$$

Solving for α and β from Equation (5) and (8) gives:

$$\alpha \simeq 2{\cdot}7$$

$$\beta \simeq 2{\cdot}5$$

The group-delay can now be determined from Equation (7) with x made small and is:

$$-\frac{d\phi}{d\omega} = \frac{2\alpha}{\omega_b} = \frac{5{\cdot}4}{\omega_b} \qquad (9)$$

It would be possible to extend the analysis to third and higher-order band-pass filters. In these cases, more parameters are available and better approximations to a constant group-delay over the pass band are attainable. However, these networks become progressively more complicated and alignment becomes more difficult, thus for these reasons a second-order network is thought to be a suitable basis for the design of a practical notch filter.

3. CONSTRUCTION AND ALIGNMENT OF THE FILTER

It is shown in Section 2 that a second-order band-pass filter provides a suitable basis for the design of a video notch filter since the bandwidth can be adjusted and the group-delay can then be made maximally flat to the fourth power of frequency. Having designed the band-pass filter for the appropriate bandwidth and maximally-flat group-delay it is then possible to calculate the actual group-delay and the delay T of Fig. 1 must now be set to this value.

Although the required values of the circuit components can be calculated, in practice it is necessary to provide adjustable elements for the final alignment of the complete filter since the resonant frequencies of the tuned circuits will be critical and will be modified by stray inductance and capacitance. If the circuit of Fig. 2(*b*) is used, it will be necessary, in practice, to precede the band-pass filter with a buffer stage. A convenient value for g can now be chosen which is somewhat less than the buffer-stage output conductance in order to allow for adjustment. The value of the remaining components can be calculated from a knowledge of ω_0, ω_b, α and β, as follows:

$$C_2 = g\alpha/\omega_b = 2{\cdot}7\ g/\omega_b$$

$$L_1 = \beta/(\omega_b{}^2 C_2) = 2{\cdot}5/(\omega_b{}^2 C_1)$$

$$L_2 = 1/(C_2\,\omega_0{}^2)$$

$$C_1 = 1/(L_1\,\omega_0{}^2)$$

$$T = 5{\cdot}4/\omega_b$$

The notch filter may now be constructed and the final alignment carried out. If, say, C_1 and C_2 are first selected, L_1 and L_2 must be adjusted to resonate with them at frequency $\omega_0/2\pi$. A final adjustment of g can now be carried out to obtain a constant group-delay characteristic and one means of achieving this is to adjust the response of the band-pass circuit to an excitation consisting of a very narrow pulse to be as nearly symmetrical as possible.

The delay T may now be connected and the final adjustments to the complete notch filter carried out. The gain and phase controls are adjusted for best cancellation of the centre frequency component of the band-pass filter, at $\omega_0/2\pi$, and the gain control is then re-adjusted in order to obtain the required attenuation in the notch stop-band.

4. CONCLUSIONS

The design of a phase-corrected video notch filter for television applications has been described which should have a performance superior to that of conventional notch filters. As a result of the phase correction, the ringing occurring at a signal transition is reduced in amplitude and spread approximately equally on either side of the transition.

5. REFERENCE

1. British Patent Application No. 5319/66.

SMW

Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey